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FERTILIZERS, SOIL ANALYSIS, AND PLANT NUTRITION

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SOIL FERTILIZING is of great importance in successful farming. There is no simple method of analyzing a California soil to predict, with any degree of reliability, the best fertilizer applications or the suitability of a soil for a certain crop. Except in rare cases, there is no quick and easy way to diagnose the needs of a soil.

THE PURPOSE OF THIS CIRCULAR is to explain general ideas of plant nutrition for readers without specialized technical training, in order to contribute to an enlarged understanding of the complexity of fertilizer problems and soil analysis in California.

THE INFORMED FARMER will realize that many factors of plant nutrition must be considered with the aid of knowledge of local experience, such as has been gathered by the farm advisor. He will realize that it is exceedingly difficult to properly analyze a large area on the basis of a single small sample of soil. When in doubt, he will find it always useful to consult his farm advisor in attempting to solve a practical problem of soil management. The farm advisor, if his own information is incomplete, can suggest the best method of seeking any useful information in possession of the Experiment Station.

ALL THE FACTORS of climate, kind of soil, and variety of crop affect fertilizer practice; and each crop on each soil is a separate problem.

FERTILIZERS, SOIL ANALYSIS, AND PLANT NUTRITION

D. R. HOAGLAND[1]

THE PURPOSE of this circular is to explain general ideas of plant nutrition for readers who lack specialized technical training, but who are interested in agricultural phenomena.

In beginning the discussion, it is useful to emphasize the extreme complexity of the conditions which govern the growth of crops. The application of scientific methods to soil problems involves many difficulties not met with in the application of similar methods to industrial processes. Obviously, the latter can be controlled to a far greater degree than can the processes of plant growth as they occur under field conditions. Once the scientific and practical problems of a mechanical or chemical industry have been overcome, any given process may be repeated indefinitely with exactly predictable results. Such an achievement is seldom possible in the field of agriculture. Plants and soils exist in extraordinary variety, and both are subject to the variable and uncontrolled influence of climate and frequently of plant diseases or insect pests.

These statements would be true of any part of the world, but they have more than ordinary significance in California, because of its exceptional diversity of crops, soils, and climate. Notwithstanding the difficulties inherent in soil problems, real progress may be hoped for by persistent research in field and laboratory, and only by this means.

CHEMICAL ELEMENTS OF THE SOIL ESSENTIAL TO PLANTS

After the water is driven off, a plant is mainly composed of organic substances derived from the elements of carbon dioxide in the atmosphere and from water in the soil. Only very small proportions of mineral elements from the soil are present in the plant, but these are indispensable; and we have some control over their supply in the soil by use of fertilizers and other methods of soil management.

The chief aspect of soil and plant relations to be dealt with in this circular concerns the processes by which crops take from the soil the mineral elements necessary for their growth. These mineral elements are usually referred to as "plant foods," although this term is frequently used to designate only the three elements potassium, phosphorus, and nitrogen. (In the present discussion, the terms potassium and potash are used interchangeably; likewise calcium and lime, magnesium and magnesia.) In an accurate sense, these elements are not foods, but part of the raw material from which plants build up the actual foods. Water and carbonic acid gas (carbon dioxide) are the other raw materials.

Of course, it is only with the use of the energy of sunlight that these raw materials can be made into the organic compounds of the plant. For this

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reason, in all problems of plant growth it is essential to consider the factor of light, or more broadly, the climatic factor. This is always interrelated with the use of inorganic elements by the crop.

In addition to nitrogen, phosphorus, and potassium, plants require calcium, magnesium, iron, and sulfur. They also require minute amounts of the chemical elements boron, manganese, zinc, copper, and molybdenum. Such elements needed in only minute amount are just as necessary as nitrogen, phosphorus, and potassium. The elements needed in minute amounts are usually present in sufficient quantities in soils, but sometimes a deficiency of one of them produces nutritional plant disease, as mottle-leaf from deficiency of zinc.

The idea that only seven soil elements (potassium, phosphorus, calcium, magnesium, nitrogen, iron, and sulfur) are required by plants, is now known to be incorrect. The normal development of crops depends also on the ability of the soil to supply minute amounts of boron, manganese (fig. 1), copper (fig. 2), and zinc. Recent research, conducted at the California Agricultural Experiment Station and elsewhere, indicates that molybdenum is also an essential element. There are occasional suggestions that minute quantities of still other unidentified chemical elements may be needed, but conclusive proof of their general essentiality has not yet been obtained.

It is reasonable to assume that boron, manganese, copper, zinc, and other elements required in only very minute amounts, can usually be supplied by the soil without special treatment, and that additions to the soil would serve no useful purpose. In general this is true, yet in the past decade, many reports have come from different parts of the world which indicate that certain previously obscure plant diseases may be prevented by applying one or another of the elements needed by the plant in only very small amounts, either to the soil or directly to the plant.

Of particular interest to agriculture in California is the disease known as little-leaf, or rosette, of deciduous trees and as mottle-leaf of citrus trees. Zinc compounds have been found to be a specific corrective for this disease. A disease of trees sometimes given the name exanthema is often cured by the use of copper compounds. In humid regions, numerous cases of boron deficiency have been discovered, and sometimes manganese is insufficiently available in the soil. Recent evidence indicates that for certain crops boron and manganese deficiencies exist in a few California soils. For example, in certain areas, response of olive trees to boron applications has been noted. Chlorosis caused by lack of available iron is common, particularly in soils high in lime.

Under California conditions, impurities in fertilizers generally will not correct deficiencies of elements needed by plants in minute amounts, because of fixation of these elements in unavailable form by the soil.

It has sometimes been suggested that one should choose commercial fertilizers in which elements needed in minute amounts are present as impurities. But the application of these elements is needed only for special crop and

soil conditions. Furthermore, when they are needed, the quantities added as impurities in a commercial fertilizer may be wholly ineffective for California soils with their generally high power of fixation, so that even the small amount of the deficient element required by the plant may not be made available. For example, from several hundred to several thousand pounds of zinc sul-

Fig. 1.—Tomato leaflets from plants growing in nutrient solution without enough manganese (left); in complete nutrient solution (right). Manganese deficiency sometimes appears in California under field conditions in fruit trees. Manganese is an essential chemical element for all crops. The leaf symptoms shown above are typical for many plants when they cannot absorb sufficient manganese. The ability of crops to absorb enough manganese (this is true also of many other elements) varies greatly with the kind of crop, even in the same soil.

fate per acre may be required as a soil treatment to correct a little-leaf condition, and in practice zinc applications are often made directly to the tree by sprays.

While a minute amount of boron in the soil is essential for plant growth (see cover), this element can become highly toxic to plants when a little more is present—even though its concentration is still relatively low. Species of plants differ greatly, however, in the amount of boron they can tolerate. The practical problem of excessive content of boron in certain irrigation waters has been given much study in California.

THE SOIL AS A NUTRIENT MEDIUM FOR CROPS

Mineral nutrients are absorbed from the soil by plant roots after they are dissolved in the moisture of the soil. Recently a more direct transfer of plant nutrients from soil colloids to roots has been suggested as an additional method of nutrient absorption. In either case the very finely divided matter of the soil (soil colloids) is of chief importance in determining how accessible a nutrient is to the plant.

The prevailing theories of plant nutrition are based on the assumption that plants can take up mineral nutrients only after the latter are dissolved in the soil water; and clearly the soil water (soil solution) is a major immediate source of these nutrients. The nitrate, for example, is nearly all present in the soil solution. Recently, however, evidence has become available that there may be an additional mechanism by which plant roots absorb nutrients.

The mechanism is concerned with relations between plants and soil colloids. These colloids are very finely divided particles of matter, and consequently have a large amount of surface in proportion to their total volume. With such substances, chemical reactions at surfaces become of special importance. Certain kinds of mineral nutrients become adsorbed by these colloids—that is, attached at their surface.

According to the recently developed theory, nutrients so held may move directly into the root when the soil colloid is in intimate contact with the surface of the fine roots, or root hairs, of the plant. The movement involves an exchange of chemical elements (ions) between the root and the colloidal particle of soil, without the intervention of the soil solution. To elaborate the new point of view would require much technical discussion, and this is unnecessary for the purposes of the present circular. Fortunately, most of the practical deductions based on the theory of the soil solution remain sound.

There are seldom present at any one time in the soil moisture sufficient amounts of all mineral nutrients to supply the needs of plants during the whole period of their growth. For example, during the season a crop may remove from the soil many times the amount of phosphate present in the soil moisture at the beginning of the season.

As far as absorption of nutrients from the soil solution is concerned, availability becomes then a question of the rates and concentrations at which essential elements contained in the solid portion of the soil can dissolve in the soil moisture. These rates and concentrations should be adequate to keep pace with the rates of intake by the plant, so that no limitation in growth will occur. A deficiency of one element will limit growth even if all others are present in abundance.

The solution of certain essential mineral elements depends primarily upon the production of acids in the soil. This in turn depends upon biological activities, that is, the activities of microörganisms and of root cells. The most important acids produced in this way are nitric, sulfuric, and carbonic. In most California soils these acids are neutralized by basic substances in the soil as fast as they come into existence. The salts thus formed dissolve in the soil moisture and become part of the nutrient medium of plants.

Fig. 2.—Tomato plant growing in nutrient solution with all essential chemical elements except copper (left); plant growing in the same solution but with a copper-containing solution sprayed on the leaves (right). The amount needed is very minute, but copper is essential for normal growth of plants. In California, copper deficiencies in the field have not been reported for tomato plants, but sometimes copper deficiency appears in fruit trees.

To illustrate, bacterial action may bring about the production of nitrate (derived originally from nitrogen present in the organic matter of the soil), a soluble and available form of nitrogen; and at the same time calcium, magnesium, or potassium will go into solution and become available to plants. These activities of microörganisms are primarily dependent upon the presence of organic matter in the soil. Organic matter thus plays an indirect part in dissolving the elements named above.

The acids produced in a soil by decomposition of organic matter by soil bacteria or fungi and the carbonic acid given off by roots are of great importance for making certain nutrients of the soil available to plants.

It is still uncertain whether this particular action of organic matter is indispensable in view of the direct action of root cells described in the next paragraph. In the case of phosphate and iron, organic matter may have a useful solvent effect in some soils because of other chemical phenomena. The great value of organic matter in the soil in improving physical condition of

the soil and providing a reserve of nitrogen has been discussed on many occasions, and this point need not be elaborated here. If *for any reason* organic matter promotes the growth of root systems, the absorption of mineral elements will be accelerated, and in that sense availability will be increased.

The second means by which acids are formed in the soil is the excretion of carbonic acid by roots. The general opinion is that no other acid is excreted by roots, but this opinion is not necessarily conclusive for all plants and all conditions. In any event, the carbonic acid excretion by roots is considered by most investigators to be of great importance, because of the very intimate contact between fine roots, or root hairs, and colloidal soil particles. The dissolving of minerals, or some of their components, can in this way take place in the closest possible proximity to the absorbing root surfaces. The acid can readily displace potassium, calcium, magnesium, and sodium from certain mineral or organic complexes of the soil, and absorption of these nutrients by plant roots will be made more rapid, whatever the exact mechanism.

THE ABSORPTION OF ESSENTIAL ELEMENTS BY ROOTS

The readiness with which plant roots can absorb mineral nutrients depends in part on a sufficient supply of air to the roots, and also on all factors which are essential to the good growth of roots. Absorption of nutrients will also depend on how well the leaves can make and supply organic food to the roots under the prevailing conditions of light and air temperature.

The total area of root surface capable of absorbing mineral elements may determine in part the ability of a plant to obtain from the soil adequate quantities of essential mineral elements. The plant is affected not only by the *kind of soil* it grows in but also by the *amount of soil* available to it. For this reason, as well as because of the water relations involved, it is important to maintain conditions in the soil favorable for root growth. For example, the formation of impermeable layers should be prevented. In their selective action, roots perform their functions normally only as a result of the activities of healthy living cells, which require a suitable supply of oxygen. Suitable aeration of roots is essential (fig. 3). Irrigation and cultivation practices affecting soil aeration are thus definitely related to the mineral nutrition of plants. Toxic substances, organic or inorganic, and injurious microörganisms interfere with normal absorption by roots.

The growth of roots is also influenced by the environment of the top of the plant, where the food and growth substances necessary for root growth are manufactured. Root growth and activity, and consequently the ability of plants to obtain essential elements from the soil, may be modified by climatic conditions, fruit production, plant disease, insect injury, and other factors.

The roots of plants do not take up the soil solution simply as it exists in the soil. Mineral elements may be removed at a faster or slower rate than the water in which these elements are dissolved. The plant should not be likened to a lamp wick sucking up the soil solution.

Different nutrients may be removed from solution (or more directly from soil colloids) at very different rates. Plants, therefore, have a selective action; but this does not mean that they possess the power to select only those substances required for their growth, rejecting all else. On the contrary, injurious substances may often be taken up by plants when they are present in the soil, and essential elements are absorbed sometimes in quantities greater than those needed for plant growth, or even in injurious quantities.

AVAILABILITY OF POTASSIUM

Deficiencies of available potassium are not common in California, but in special cases may occur. There is never a deficiency of potassium in total amount in the soil. The question is whether it is available to the plant. The understanding of this question and that of the use of potassium fertilizers depends partly on knowledge of the extent to which potassium is made too difficult to absorb by the plant roots because of fixation of potassium by the constituents of the soil.

Assuming that the production of acids by microörganisms or by plant roots proceeds at a satisfactory rate, is it certain that potassium will enter the root at the rates necessary for satisfactory crop growth? This depends upon the nature and status of the mineral and organic matter which holds potassium. The colloidal part of the soil is especially important in determining whether or not a soil can supply to a plant adequate amounts of potassium.

The amount of potassium easily dissolved by fairly dilute acids (such as one-quarter per cent nitric acid) comprises only a small fraction of the total amount of potassium contained in the soil. The supply of this more easily dissolved potassium has an important bearing on the concentration of potassium capable of being maintained in the soil moisture, or readily absorbed by roots, although the relation is not a simple one. In general, it may be said that the capacity of potassium to dissolve in the soil moisture is much more important than the total percentage of potassium present in the soil. But a high percentage may be not without significance if it implies a greater number of contacts between root surfaces and potassium minerals. The fineness of division and the chemical nature of such minerals is important in this connection, as well as the physiological character of the plant.

Experiments with a considerable number of California soils, carried on in Berkeley over a long period, show that continuous cropping reduces the supply of available potassium, as determined by tests with dilute acids. In some soils the amount of the reduction in this supply is nearly as great as that of the total potassium removed in the crop.

If a soil becomes depleted in the easily soluble forms of potassium, plants will have a relatively less favorable medium from which to absorb this element. But it does not necessarily follow that crops will always make unsatisfactory growth when the more soluble types of potassium are exhausted. Some crops may still find it possible to take out of the soil adequate amounts of this element for an indefinite period of time. If the plant roots have a sufficiently large area of actively absorbing root surface, and if the growth cycle of the plant gives

adequate time for absorption, a suitable adjustment may take place, even in soils which never contain in their soil moisture more than a slight concentration of potassium. Of course if the potassium-supplying power of the soil falls too low, plants will fail to thrive without proper fertilization of the soil with potassium.

In some of the humid regions of the world, deficiencies of available potassium in the soil occur frequently; but they are not common in California, although a few types of soil are now definitely recognized to be low in available potassium.

There is the additional very important idea to be considered, that different kinds of plants may differ in respect to the amounts of potassium required for their type of growth. Most agriculturists believe that plants producing large amounts of starch or sugar have a high potassium requirement, although the function of potassium in plant growth is by no means fully understood as yet. Such plants are considered to give the most satisfactory yields on soils containing relatively large amounts of potassium in easily soluble form. These ideas are chiefly based on experience in other parts of the world. It is not yet known whether or not crops of the type referred to would respond to potassium fertilization when grown on the majority of California soils. In a few cases the evidence is positive, and in many others negative.

At this point, it should be noted that many experiments indicate that the percentage of potassium in certain parts of the plant can be increased by increasing the amount of available potassium in the soil through fertilizer additions, unless the soil can already supply all the potassium the plant can absorb. The increased amount of potassium contained in the crop, beyond a certain percentage, would be superfluous in that it would lead to no increase in growth or improvement of quality—in fact, might have unfavorable effects. Such excess absorption of an element is sometimes termed a "luxury consumption."

The amount of potassium required by a crop may vary with climatic conditions. Certain field experiments in Europe and studies on plants grown under controlled conditions in California, and elsewhere, suggest that the potassium requirements of plants are altered by changes in light or temperature. The requirement by fruit trees will increase with heaviness of bearing. The importance of age of tree and of climatic environment in relation to the amount of fruit borne by the tree is illustrated by studies on prune dieback.

AVAILABILITY OF PHOSPHORUS

In some types of soil, phosphorus, like potassium, may be fixed in such a resistant form that it is unavailable to the plant. Success of fertilization of the soil with phosphate depends on whether the phosphate added to the soil actually reaches the absorbing roots in available form.

The total amounts of phosphorus present in ordinary soils are far smaller than the total amounts of potassium, but the problem of solubility is similar. To give an illustration of extreme conditions: two California soils were compared, each containing approximately the same total amount of phosphorus. Practically no phosphorus was dissolved from one soil by a relatively weak

acid; while from the other soil, treated in the same way, more than half of the total phosphorus was dissolved. Many (but not all) agricultural plants make very poor growth in the first-mentioned soil because of lack of available phosphorus; while in the second soil there is no deficiency of this element.

The question of phosphate availability is, however, much more complex than the simple illustration just given would imply. Some evidence gives a basis for dividing the phosphate of the soil into two classes: that which dissolves in dilute acid and that which does not dissolve in dilute acid but which is released into alkaline solutions, as a result of special chemical reactions of soil colloids.

The availability to plants of phosphate held by the colloid depends upon the total amount of phosphate present in this form. The greater the amount of phosphate, relative to the amount of colloid, the greater the availability of phosphate will be.

In many soil systems the availability of phosphate is associated with the capacity of the soil to neutralize acids as they are formed (buffering capacity). If this is high, the plant may be prevented from acquiring potentially acid-soluble phosphate. Thus phosphate may be relatively unavailable in a soil containing a large amount of lime.

In certain types of soil high in iron, phosphate is only slightly available to plants. The phosphate present in some iron complexes is not readily soluble, even under slightly acid conditions.

The discussion of phosphate availability requires consideration not only of the chemistry of the soil but also of the biological factors involved. Different kinds of plants vary immensely in their power to secure adequate amounts of phosphate from soils of low phosphate availability. The extent of surface of the root system and the length of the growing season may in part explain this variation. Conceivably, another partial explanation is that the roots of certain species of plants excrete, or leave as a residue, organic acids, some of which are known to have the power to displace phosphate from soil colloids high in iron.

Fruit trees offer one example of crops capable of obtaining enough phosphate from soils of extremely low phosphate availability—soils in which most annual crops might fail for lack of phosphate. There is little evidence that fruit trees in California respond to phosphate fertilizer, even when some other crops in the same soil may show large response.

It is hoped that this discussion, although very incomplete, will nevertheless make it clear how complex the question of availability of potassium and phosphate is. Attention must be given, not only to the soil type, but also to the type of crop, to conditions in the soil favoring or inhibiting root growth, to the organic-matter content of the soil, and to climatic environment.

USE OF NITROGEN AND OTHER FERTILIZERS

Having sketched a few important general relations existing between crops and soils, certain views concerning fertilization will now be considered. In the first place, it is important to realize that some type of fertilization is required, sooner or later, for most crops under modern agricultural conditions. If we

Fig. 3.—Tomato plants growing in complete nutrient solution with air bubbled through the solution (left); plants growing in the same solution without aeration (right). For nearly all crop plants, roots and the top of the plant do not make good growth without adequate aeration of roots. Aeration in soil is as necessary as it is in nutrient solution. The aeration of soil depends on the kind of soil and on methods of cultivation and general soil management. In part, the availability of essential chemical elements depends on adequate aeration of soil, which promotes root growth and absorption of essential elements by the roots.

take a general average of experience throughout the world, we find that special concern is felt about maintaining available nitrogen in the soil, although in many regions when the cropping system includes legumes, phosphate is the dominant need. Crop responses to nitrogen applications, although not universal, are met with under the greatest possible variety of soil, crop, and climatic conditions. The nitrogen requirements of many crops are very high.

Nitrogen is the element usually most effective in fertilizing California soils. It can easily be lost from the soil by leaching or by loss to the atmosphere through action of soil bacteria.

When nitrogen is in the form of nitrate it is subject to leaching. But it may also be lost in gaseous form. In this connection experiments made in Berkeley are of interest. Thirteen soils, from different parts of California, were studied over a period of many years with reference to their total content of nitrogen under both cropped (barley) and uncropped conditions. The losses of nitrogen from the cropped soils resulting from the activities of microörganisms were much greater than the losses of nitrogen in the crop removed.

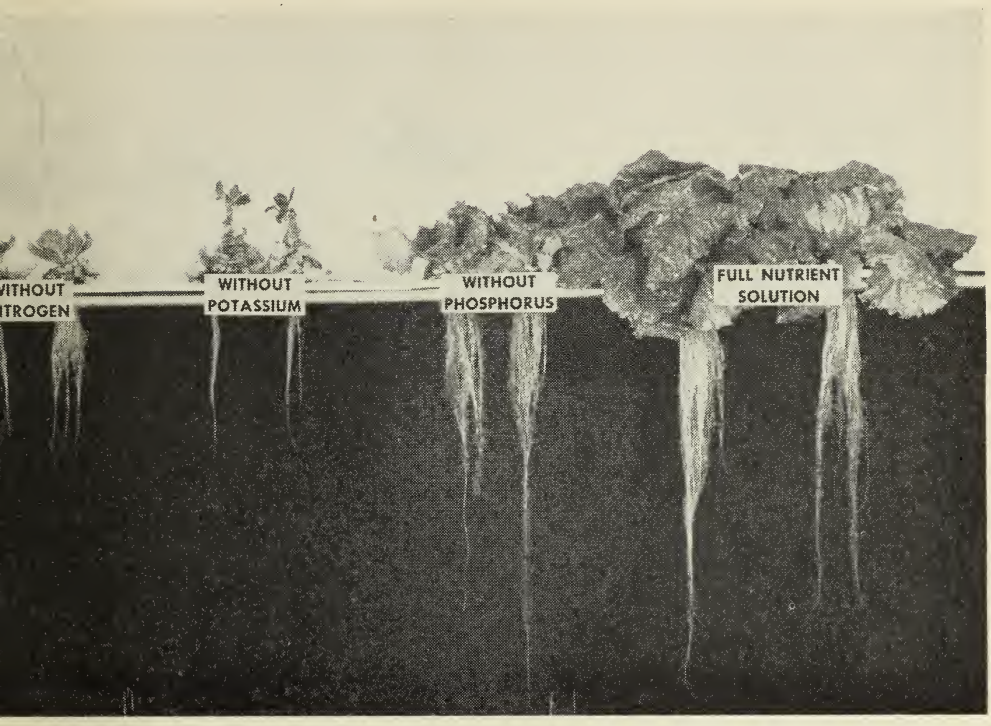

Fig. 4.—Growth of lettuce plants without nitrogen; without potassium; without phosphorus; and in a complete nutrient solution, containing all chemical elements necessary for plant growth.

After a period of cropping, the soils referred to reached a low level of crop production, but the total nitrogen in the soil changed only slightly from year to year. The large losses of nitrogen occurred during the earlier years of the experiment, when nitrate production was high. The content of nitrogen and of total organic matter in a soil depends on climatic conditions. When sufficient moisture and oxygen are present in the soil and soil temperatures are high, oxidation of added organic matter occurs with great rapidity. This is true under many of the soil and climatic conditions of California.

Much further work must be accomplished before the nitrogen economy of the soil is sufficiently understood, but it is evident that losses of nitrogen may be great under some circumstances.

These facts may help to explain why nitrogen additions to the soil are so frequently beneficial, whether accomplished by the growth of legumes or by the use of animal manure or commercial forms of nitrogen. With all questions relating to nitrogen, it is of the utmost importance to consider the activities of the soil microörganisms and the possible influence of irrigation and cultivation practices and additions of organic matter on these activities. Addition of organic matter with too high a ratio of carbon to nitrogen—for example, cereal straw—leads to a temporary loss of available nitrogen (nitrate). This is because the nitrate is utilized by microörganisms when their rapid multipli-

cation is made possible by the energy furnished by the carbohydrate. For a greater or lesser period of time the crop may suffer from nitrogen deficiency under those circumstances, unless a suitably large amount of nitrogen fertilizer is added to the soil at the same time.

CHEMICAL EFFECTS OF THE SOIL ON ADDED FERTILIZERS

To understand the fertilization of a soil with phosphate or potassium, one needs to recognize that these substances react chemically with the soil. The point of interest, as far as crop growth is concerned, is the resultant condition of the soil after fertilizers or other amendments are added. The same fertilizer will produce different effects in every different soil.

Sometimes reference is made to the use of "balanced fertilizers." The balance that is important is not in the fertilizers, but in the soil after the fertilizer has been added and has reacted with the soil. A fertilizer cannot, in any accurate sense, be compared with a balanced ration for an animal. The feeding of animals with organic nutrients and the absorbing of mineral elements by plants are entirely different in nature.

Potassium (potash) reacts in soils chiefly with colloidal substances. In this reaction some of the potassium added may be fixed (attached to the colloid) and go out of solution, and calcium (lime) or magnesium (magnesia) enter into solution to take the place of the potassium. Generally, in soils of fairly heavy character, nearly all the potassium added in an ordinary fertilizer application is fixed in this way, liberating calcium, magnesium, and similar elements.

Potassium fixation is of great interest in the fertilization of fruit trees under California conditions, for in many soils most of the potassium added may be fixed in a surface zone, out of reach of most of the absorbing root system. Therefore, in soils of high fixing power it is especially difficult, or even economically impractical, to alter the condition of the soil in contact with the roots developed very far below the surface zone. Recently, however, a few positive results have been reported, with potash fertilizers applied below the surface zone of soil in prune orchards.

In many soils, when plant roots develop close to the soil particles on which the fixation occurs—as with shallow-rooted crops—much of the fixed potassium can be absorbed by the plant. This is true of certain California soils of high fixing power of potassium, in experiments with plants such as wheat, barley, tomatoes, and beets. The fixation of potassium in such cases is not so firm as to prevent it from being absorbed by the plant at the zones of contact between roots and soil particles. The plant is an active agent in the process, because of carbonic or other acids which may be excreted by roots, and because of the rapid removal of potassium from the soil moisture or soil colloids by the growing plant. This action makes it possible for new supplies of potassium to enter the plant continuously as long as a suitable source of potassium remains in the solid portion of the soil. The previous discussion of root and soil-colloid contact phenomena should also be recalled at this point. It is clear from all these considerations that the location and rate of growth of root

systems, the method of applying the fertilizer, and the fixing power of the soil are very important factors in fertilization.

In some soils part of the potassium added is fixed so firmly that it becomes relatively unavailable to plants, even if there is proper contact between roots and soil containing the element.

Phosphate, as well as potassium, when added to a soil will undergo chemical change, although the chemical reactions involved are different from those with potassium. Phosphate easily soluble in water before addition to the soil usually becomes much less soluble afterward. Consequently, in most soils it is very difficult to change the soil condition very far below the zone in which the phosphate fertilizer is mixed with the soil. Some penetration may at times be obtained by use of unusually large amounts of fertilizer, by effects of organic matter, or by special methods of application.

Just as with potassium, the fixation of phosphate may not prevent plants from absorbing at least some of the phosphate added in a fertilizer, provided, again, that sufficient root development occurs in that portion of the soil to which the phosphate is added, or to which it penetrates. A striking example of this is found in certain California soils of high fixing power, in which some crops make hardly any growth because of the insolubility of the phosphate naturally present. Yet the addition of certain soluble phosphates to these particular soils has an extremely beneficial effect on various surface-rooted crops.

The manner in which plant roots absorb phosphate in such cases is only very slightly understood as yet; but no doubt stress can be placed on the intimate contact between roots and soil particles, and on the finely divided and reactive nature of the compounds formed when phosphate is added to soil.

With certain methods of application, there may occur direct contacts between roots and particles of soil saturated with phosphate, or even still unchanged particles of some types of phosphate fertilizer. The proper placement of the phosphate by localized application to the soil is often the key to successful fertilization.

There is evidence, however, that it is possible for a part, and sometimes a major part, of the added phosphate to undergo such firm fixation that it becomes unavailable to plants, even when root contact takes place. This loss of availability may be more rapid with some forms of phosphate than with others. These remarks do not apply with equal force to all types of soil, and, furthermore, the method of applying the phosphate fertilizer modifies any comparisons of different types of phosphate fertilizers. In the California soils investigated, it does not appear that added potassium can become unavailable to nearly the same extent as phosphate does in certain types of soil.

Nitrogen in the form of ammonia nitrogen is also at first fixed by soil colloids, but later nitrification takes place and the nitrate readily moves downward. Thus availability to plant is only temporarily influenced by the fixation.

From the foregoing considerations, it is evident that when crops are not too deep-rooted, it is possible, at least for a time, to modify the nutrient condition of a soil with respect to phosphate and potassium by the use of suitable fertilizers, applied in reasonable amounts. But the practical question is how widely phosphate, potassium, and nitrogen fertilization can be used profitably. Concerning this point no general statement can be made. The kind of

soil, its previous agricultural history, the amount of potassium or phosphate already removed by crops, the crop to be grown, and the climate, all must be considered. Many soils may maintain their productivity for a long period with the addition of only one or two of the three elements, nitrogen, phosphorus, and potassium, because the remaining elements are still supplied in sufficient abundance from the reserve already present in the soil. A balanced condition for crop growth might be brought about in a soil, at least for a long period, by the simple addition of nitrogen in appropriate form.

These conclusions are in no way inconsistent with recognizing that continuous and intensive cropping in general tends to lower the amount of easily dissolved phosphate or potassium, even in soils of high initial fertility, such as are often found in this state.

The growth of crops tends to decrease the amount of available potassium or phosphorus in a soil, but in California it does not necessarily follow that a crop will respond, at least until after many years of cropping, to fertilization with potash or phosphate. Sometimes, however, deficiencies of these elements may be currently present or may arise in no distant future. Each case must be considered specifically.

The question which has to be asked for each soil is: Has a critical point been reached, or will it be reached soon, or is a state of depletion still far in the future? The answer to this question will be modified in accordance with the nature of the crop as well as the soil; for, as already indicated, some crops, under otherwise favorable conditions, may be able to absorb sufficient potassium or phosphate from slightly soluble compounds, often considered unavailable. These are present in most soils in amounts that are very large relative to crop withdrawals. In numerous California soils, potassium regarded by the soil chemists as inert, as judged by chemical agents, may nevertheless be slowly available to crops.

Sometimes sulfur may be deficient in a soil; this has been found true of a number of California soils on which leguminous crops are grown.

In humid regions, magnesium deficiencies have been noted in some soils, especially those of sandy character. Few studies have been made on the possible occurrence of magnesium deficiencies in California.

Calcium deficiency is discussed under "Acid and Alkaline Soils" (p. 20).

However these questions may be decided for particular cases, the general statement can be made that serious soil difficulties will arise in course of time under conditions of exhaustive cropping, unless provision is made for additions to the soil. Additions may be by means of covercrops, animal manure, nitrogen fertilizers, or other commercial fertilizers, or by some combination of these materials. The chemical, physical, and biological states of the soil are all involved. The maintenance of productivity will not be indefinitely automatic, although certain California soils seem to be initially so well supplied with available nutrients that development of marked deficiencies—except of nitrogen—may be long delayed.

COVERCROPS AND ROTATION OF CROPS

From general experience, the importance of crop rotation, when feasible, is to be emphasized. But sometimes by proper soil management the same crop may be grown successfully for very long periods.

The turning under of covercrops may tend to build up the soil reserve of easily available potassium and phosphate. Aside from effects of organic matter already discussed, this action is explained by the gradual accumulation in the growing plants of phosphate and potassium derived from very slightly soluble compounds present in the soil, including the deeper zones. The entire amounts accumulated in the plant tissues, when returned to the upper part of the soil, may remain in an easily available form for other crops.

How important these changes are in California soils is not yet known. Plants grown on soils containing very small amounts of available potassium or phosphate are likely to have relatively low percentages of these elements present in their tissues. Consequently, there would be this limitation to the possible increase in availability of potassium and phosphate through the use of covercrops. Also the power of some soils to fix potassium or phosphate in more or less unavailable form tends to limit the building up of a supply of available nutrients.

Covercrops, however, may have great importance for reasons other than those related to availability of phosphate or potassium. It is particularly necessary to stress the effects of organic matter and of growing roots on the penetration of water and on aeration and also on the maintenance of the soil supply of nitrogen.

In many parts of the world which have had longer agricultural experience, the practice of continuously growing one crop often gives very unfavorable results. In such cases, suitable rotations of crops, including legumes, frequently accompanied by the use of phosphate or other fertilizers, have been worked out through long periods of field experience.

The desirability of crop rotation is not necessarily to be attributed merely to the maintenance of nitrogen content in the soil, or possible differences in the abilities of different crops to utilize relatively insoluble potassium or phosphate, however important these factors may be. Some investigators emphasize the development of injurious soil microörganisms, plant diseases, or toxicity caused by residues of crops. There are cases in which it has been possible to grow the same crop successfully for many years, when animal manure, or commercial fertilizers, or both, have been applied in suitable amounts; but, in general, rotation of crops, if feasible, is sound practice.

USE OF ANIMAL MANURE

Considerable quantities of potassium and phosphorus, as well as nitrogen, are added to the soil when large amounts of animal manure are systematically applied. From earliest times, the observation has been made that the use of animal manure nearly always produces highly favorable effects on the growth of plants.

Fig. 5.—Growth of tomato plants in a soil well supplied with fertilizers, including animal manure; in inorganic nutrient solution, without organic matter; and in pure sand, irrigated with inorganic nutrient solution. This is an example of the principle that most crop plants can make full growth without organic matter, if all the required inorganic nutrients are available. The organic substances are made by the plant itself, in its foliage.

This question has been under careful study at the Rothamsted Experimental Station, England, for approximately a century. Several years ago a review at the Rothamsted Station of results of experiments up to that time on continuously cropped plots of wheat showed that yields were about the same for plots fertilized with artificial fertilizers and with animal manure. The organic matter of manure is valuable in some soils in helping to maintain a good physical condition in the soil, but other forms of organic matter (such

as covercrops) may accomplish the same purpose; also procedures of cultivation or irrigation are of prime importance in their influence on physical factors of the soil.

The possibility that animal manure, or other organic matter, may contain, or cause the microbiological production of, organic substances of hormone- or vitaminlike character beneficial to the crop has been discussed. But there seems not to be any good evidence to support the view that this type of effect is of practical consequence as far as crop plants under agricultural conditions are concerned. Such plants themselves manufacture all the organic substances utilized in their growth. The function of the soil is to supply mineral elements and water, and to provide anchorage for the plant.

Artificial fertilizers under proper conditions of soil management may often give results comparable to those obtained by animal manures. Manure is valuable but is sometimes not a satisfactory or economical method of supplying needed nutrients; and even if it were, there is not enough of it for all the soils that need fertilizing.

Although the use of manure may largely solve a problem of soil fertility for certain crops or districts, it is obvious that this is not a universal solution of soil problems. Adequate quantities of manure frequently are not available, and, furthermore, if manure is produced on one soil and applied to another, there is still a question of fertilization of the soil from which the nutrients contained in the manure were withdrawn. It cannot be denied that under modern agricultural conditions, commercial fertilizers of one type or another must in the long run play an indispensable part, subject to such limitations as this circular attempts to describe.

OBSERVATIONS ON ROLE OF ORGANIC MATTER

Controlled experiments show that crops do not require organic matter in itself. But the indirect effects of organic matter in the soil may be of extreme importance.

The value of organic matter in the soil in improving the physical condition of the soil, or aiding the penetration of water, has been mentioned, but this aspect of organic matter in soils is outside the main theme of this discussion. The question is more fully and critically treated in other circulars or bulletins pertaining to irrigation or general soil management.

In special experiments in greenhouses many types of plants of agricultural interest have been grown successfully without organic matter, in pure sand to which only inorganic nutrients have been added (fig. 5). From these experiments one may draw the conclusion that organic matter, as such, is not necessary for crop growth. The effects of organic matter in the soil are in that sense secondary, however important they may generally be. It is more enlightening to discover just what these secondary effects are than merely to assign great importance to organic matter on the basis of vague generalizations.

FERTILIZATION AND QUALITY OF THE CROP

The problem of the effect of fertilizers on quality of crop is exceedingly complex. An effect may be most logically expected when there is a marked deficiency of nutrient elements in the soil. Sometimes excessive use of nitrogen may impair quality of certain fruit crops, even when enough potassium or phosphate is present in the soil in available form. Specific conclusions about the effect of fertilization on quality of a crop should not be drawn without careful study of the particular soil and crop in question. Broad generalizations should be avoided.

It seems evident that the quality of crops may be influenced by fertilizer applications under some soil and climatic conditions. The improvement or change of quality occurs primarily in soils which are initially very deficient in ability to supply one or more nutrient elements. Many of the reports dealing with the effects of fertilizers on quality of crops are based on experiments carried out under soil and climatic conditions different from those found in most parts of California.

Much discussion has taken place concerning the possible influence of potassium or phosphate fertilization on quality of crop as distinct from yield. Numerous observations indicate that fertilizers applied to deficient soils may alter the rate of growth or time of maturity of various crops. For example, phosphate, when applied to soils deficient only in this nutrient, may accelerate root development and promote tillering and grain formation in cereals. With plants of this type, the presence of adequate amounts of available phosphate in the soil during the early stages of plant growth seems to be very important. Again, applying potassium to a soil deficient in available potassium tends to produce plumper seed in the case of cereals. None of the effects just mentioned will be observed if the potassium or phosphate already present in the soil is sufficiently available.

With fruit trees or vines, it is extremely difficult to obtain convincing results concerning effects of potash or phosphate fertilization on quality of fruit under field conditions in California. Most reports by investigators in California have been negative or inconclusive, although study of this question is not closed. Recently certain definite observations on quality of fruit have been made on citrus trees, growing under carefully controlled conditions in artificial media. The conclusions reached were not always in accord with generally held ideas.

Heavy nitrogen fertilization may *impair* commercially desired quality in some fruits, and this adverse effect of heavy nitrogen applications may appear even though abundant available phosphate and potash are present in the soil.

Yield or quality, or both, may be affected by soil conditions producing disease, but in most cases the disease is not produced by deficiency of potassium or phosphate. In certain restricted districts, however, deficiency of potassium is an important factor in a nutritional disease of prune trees.

Field observations in various parts of the world have sometimes been thought to show that an inadequate supply of potassium renders plants less resistant

to the attack of certain plant diseases produced by bacteria or fungi. The possible relation of fertilization with phosphate or potassium to some kinds of plant diseases produced by microörganisms is a subject of great interest. Unfortunately, the investigational work is extremely complicated, and we do not now have any adequate working knowledge. It is not unreasonable to suppose that with some, but by no means all, diseases produced by organisms, plants are more likely to suffer serious injury when in a state of malnutrition. A marked deficiency of an essential element leads to an abnormal change in the organic composition of plant tissues, and this may make the plant more susceptible to attack by microörganisms or by insects. On the other hand, excessive use of nitrogen may produce a succulent plant of low resistance to certain diseases.

The term "quality" is a very general one. Any claim that a fertilizer treatment improves the quality of a crop is not convincing unless quality is specifically defined for the crop concerned and the effects of a fertilizer definitely measured. Also important to bear in mind are the often dominant influence on quality of climatic conditions and of the inherent hereditary characteristics of the variety of crop grown. The immense general importance of soil management and fertilization should not lead us to minimize the factors of climate and of plant heredity when discussing methods of improving quality in a crop. Obviously, insect injury and plant disease caused by microörganisms may become the dominating factors affecting quality.

PLANT NUTRITION AND NUTRITIONAL VALUE OF CROPS

The effect of the soil on the nutritional value of a crop for feeding animals or for human consumption is under active investigation by several institutions, but conclusions not verified by reliable investigational institutes should be viewed with skepticism. Occasionally plants may not contain enough of certain chemical elements for the needs of animals, especially grazing animals. An expert in plant or animal nutrition should always be consulted before making any assumptions on this point in a specific instance.

The subject of the quality of crops in relation to the nutritional value of the crop for animals or humans has recently been receiving a large amount of attention and is being specifically investigated at a special federal laboratory at Cornell University. The questions involved are exceedingly complex, and many cannot be answered without years of scientific study. Statements on this subject are sometimes made in newspapers, popular journals, or in "health books," which have no adequate scientific foundation, or which may be misleading. Reliable information, as far as it is available, should be expected from publications of the federal government, state experiment stations, or recognized institutions of medical research.

There is evidence that some plant products produced in certain soils may be nutritionally deficient in one or more mineral elements needed by animals or humans—for example, calcium, phosphate, iodine, iron, manganese, copper, or even in rare cases cobalt. But when the food products consumed are varied

and come from many sources, such nutritional deficiencies in composition are not likely to occur in any serious degree. Furthermore, the plant tends to maintain within a limited range of values, the mineral composition of its seed or fruit (part of its reproductive system). This composition is subject to only relatively small changes through the influence of fertilizers, in amounts ordinarily applied to a soil. The major variations in mineral composition are usually found in the vegetative parts of the plant, particularly the leaves or stems. For example, a tomato fruit cannot be made a nutritionally rich source of calcium by soil fertilization. In this respect it will always be far inferior to milk. To say that a tomato has been "mineralized" is misleading.

There is reason to believe that in determining the vitamin content of a plant, the hereditary characteristics of the plant and the climate generally may be more important than the mineral nutrition of the plant.

Many claims have been made that an increase in supply of a particular element in the soil may promote increase in the concentration of some vitamin in plants. The question is still under study, but recent evidence so far suggests that climatic conditions, especially the factor of light, may be more important than mineral supply in determining the content of certain vitamins in the plant. Special knowledge has been gained of vitamin C on this point. The vitamin content of a plant may also vary widely according to the variety grown, even when all other factors are constant.

ACID AND ALKALINE SOILS

Many inquiries are made concerning the acidity or alkalinity of soils. All soils have either neutral, acid, or alkaline reaction in the soil moisture. This reaction is usually subject to certain fluctuations, according to moisture conditions, amount of carbon dioxide present, and other factors. By a neutral reaction is meant one which is exactly the same as that of absolutely pure water. The degrees of acidity or alkalinity are designated by the symbol pH. pH 7 means a neutral reaction; values below 7 indicate acidity, and values above 7, alkalinity. A soil of pH 5 is decidedly acid; one of pH 9, decidedly alkaline. A great many soils in this state have reactions not far from the neutral point.

Markedly acid soils are common in some regions, but they are comparatively rare in California among the agriculturally most important soils. Soils of this character may be found in those areas of the state that have a high rainfall.

Highly alkaline soils also occur, but a discussion of these soils would make necessary a consideration of alkali conditions, which are discussed in other publications of the Station.

The reaction of a soil is subject to change resulting from the action of substances added to the soil. Thus, sulfate of ammonia may tend to increase acidity, and nitrate of soda to lessen acidity, or to increase alkalinity. Sulfur tends to increase acidity or to decrease alkalinity. These changes are associated in part with biological activities of microörganisms or of plants. Lime decreases soil acidity by chemical reaction with the soil.

It is difficult by the use of ordinary fertilizers to bring about appreciable changes in the reaction of a soil within a limited period of time, unless the soil is of a light or sandy character and has a low resistance to change of reaction through the addition of acid or alkaline materials.

It should not be assumed without special information concerning the character of the soil that lime or other substances are required to change the reaction.

With most plants of agricultural interest, a considerable latitude in soil reaction is consistent with good growth. An acid soil is not necessarily unproductive. For example, certain rather acid peat soils, when properly fertilized, are very productive. The reaction, or pH, of a soil is merely *one* factor influencing growth, and the determination of this value, important as it is at times, seldom or never should be relied on as a guide to understanding soil conditions, without a suitable knowledge of other factors.

The relative amount of *calcium* held by soil colloids under different conditions of soil acidity or alkalinity is of paramount significance. A highly acid or alkaline soil may be unfavorable to plant growth largely because of its inability to supply enough calcium to the plant. Also the availability to crops of iron, manganese, and phosphate as affected by acidity or alkalinity may greatly influence plant growth.

For these and other reasons there is no sound basis for attempting to list crops according to their preferences for degrees of acidity or alkalinity (pH values). Each soil demands special study of all the complex factors involved. Merely measuring one value of the soil, such as that represented by the symbol pH, may lead to wrong conclusions, under California soil conditions.

SOIL ANALYSIS

Perhaps this presentation of the complexity of soil problems has made clear that routine chemical analyses alone cannot often determine the adaptability of soils to crops, or the best method of fertilization. True, special investigations on soils, and the understanding of general principles, cannot progress without the use of chemical methods, but really adequate studies are costly. They can be carried out by the Experiment Station only in selected cases, to obtain knowledge of general relations, or to aid in the planning or interpretation of field experiments. The validity of any interpretation of chemical data must rest finally on the results of experiments with plants.

Even if there were now available assured methods of obtaining and interpreting chemical data on soils in terms of crop growth, there would still remain the question of securing representative samples of soil for examination. The most uniform field in appearance may, in fact, contain numerous soil variations. Hence it is extremely difficult to obtain samples which reflect an average condition. In addition, there is the question of the relative importance of samples of soil taken from different depths, which would vary with the rooting habit of the crop, physical and chemical character of the different soil layers, and irrigation practice.

In considering soil examination by the method of water extraction, it should be recalled that the soil moisture does not have a constant composition. In fact, the composition may vary from day to day. The rapid growth of certain crops may bring about a temporary depletion of substances dissolved in the soil moisture, even with the most fertile soils. Therefore, if methods of this type are to be used, one must recognize that different results may be obtained when samples are taken at different times of the year. The investigations of recent years emphasize the necessity of including studies on the solid portion of the soil, in order to understand its ability to continue supplying nutrients to plants. The supply of available nitrogen depends on seasonal microbiological activities which cannot be appraised by a single simple test.

Occasionally soils are found on which comparatively simple chemical tests may strongly suggest a deficiency of potassium or phosphate, but such soils are often extreme enough in character so that the general nature of the deficiency is already recognized by practical observations.

Most requests for soil analyses in California are made because of a desire to evaluate a soil which is neither markedly deficient in any nutrient nor outstandingly fertile. These are just the cases in which an interpretation of a soil analysis is likely to fail of its purpose. The main successes of soil analysis are with soils either extremely high in an available nutrient, or else extremely low—soils in which the need for any analysis is not pressing.

The same limitation applies to diagnosis by plant analysis, as described below; still it is believed that this method may afford a more useful appraisal of soil deficiency or of nutrient availability than methods of soil analysis.

No simple method of analyzing a California soil is known by which the best fertilizer applications, or the suitability of the soil for a certain crop, can be reliably predicted. Many factors must be considered with the aid of knowledge of local experience, such as has been gathered by the farm advisor. Furthermore, it is exceedingly difficult to take a small sample of soil which properly represents a large area.

Any possible future development tending toward a more general application of chemical tests to soils must be the result of comprehensive controlled experiments with different crops, as well as of a more critical study of field experience than it has yet been possible to make in most parts of the state.

The great diversity of crops, soils, and climatic conditions in California make the problem of interpreting chemical tests on soils far more complex than in those states in which routine chemical tests are widely employed. Nevertheless, a careful survey of soils is being made with reference to the application of recently devised chemical and biological tests. Special attention is directed to extending our knowledge of potassium and phosphate availability in California soils. Eventually the results of field experiments should clarify the significance, or lack of significance, of the tests.

PLANT ANALYSIS FOR DIAGNOSING SOIL DEFICIENCIES

Investigations are being made to determine whether the analysis of plants growing on a soil may disclose which, if any, nutrients may be deficient in the soil. The plant itself reflects all the complex factors involved in its nutrition. But in this method of diagnosis it is necessary to take account of standards for the crop concerned and the period of growth when the plant sample is taken. There is no quick and easy way to diagnose the needs of a soil, except in rare cases.

Since the previous edition of this circular was prepared, much interest has developed in another method of appraising deficiencies in the ability of a soil to supply nutrients to a crop, especially the nutrients nitrogen, phosphorus, and potassium. The method referred to is that of analyzing the plant rather than the soil, sometimes termed plant analysis or foliar diagnosis. Usually the whole leaf, the stem, or the petiole of the leaf is analyzed for the nutrient elements being studied.

The procedure is based on the idea that the plant itself is the best index of the extremely complex system of soil, plant, and atmosphere. The guiding thought is that a plant not suffering from a nutrient deficiency contains in its tissues a percentage of each nutrient element above a certain low percentage (critical percentage). Percentages below this point would then indicate that the plant is more or less starved for the element in question.

It is not expected that any one exact point could be fixed as a critical percentage. Rather a narrow range of values would be established for each nutrient element, below which a deficiency of the element in available form is indicated to exist in the soil for the particular crop under study. Since the critical range would be different for each nutrient and for each crop, careful investigation is first necessary to establish standards against which any new set of data may be evaluated.

Analysis of plant samples taken in haphazard way would have little value. The probability that a deficiency of a nutrient element exists is greater the lower the percentage of the element in the plant below the critical percentage and the earlier the low value appears in the stage of growth of the crop. The proper part of the plant needs to be selected, and above all, the samples must be taken at an appropriate stage of growth of the crop. Sometimes, in fact, samples should be taken at several different periods.

At present it would be premature to use this method as a general service method. It is still under study to determine its practical value. One objective is to aid in the selection of fields on which there is at least a probability that the soil may be deficient in one or more nutrient elements, and then to establish appropriate fertilizer tests on these soils. This is less expensive than to make fertilizer tests in a hit-or-miss fashion. Furthermore, the analysis of the plant itself in some cases gives such strong indication that the ability of the soil to supply a nutrient element is adequate that consideration of a deficiency may be dismissed with considerable confidence.

Sometimes a crop does not respond to the application of a fertilizer to the soil, when nevertheless there is reason to suspect that the crop is not ade-

quately supplied with the particular nutrient element in question. The method of plant analysis is then useful to determine whether or not the crop actually absorbed the element from the fertilized soil. There are various reasons why the plant might not benefit from the nutrient applied to the soil. These include the fixation of a nutrient element by soil colloids, insufficient amounts of fertilizer applied, injury to roots from alkali conditions or from plant disease, and the like.

The frequent increased growth of a crop by the application of nitrogen may lead eventually to deficiency in the supply of another nutrient element to the plant. The use of plant analysis may be helpful as an index of such deficiency. Altogether, the method of plant analysis seems to provide a useful tool of investigation. Its more extended application cannot be predicted in advance of further investigation, and this is necessarily slow and laborious.

Soil and plants are altogether too complex to permit of any easy or quick way of determining the best methods of soil treatment apart from exceptional cases. There must be a patient accumulation of knowledge gained in several ways: (1) by continued investigation of basic relations which enter into soil problems everywhere; (2) by further practical observation and experience; (3) by very carefully conducted and long-continued pot experiments and local field tests or experiments, preceded or accompanied when necessary by special chemical and physiological studies. Increasing attention is being given by the Experiment Station to studies of soil productivity in relation to the use of fertilizers. Systematic pot experiments on the relative productivity of important types of soils are under way.

WHERE TO GO FOR HELP WITH FERTILIZER PROBLEMS

Immediate practical steps to be taken cannot be decided upon without reference to local conditions, and none of the statements contained in this circular should be construed as a specific recommendation for any kind of soil treatment.

The College of Agriculture of the University of California is often able to help in the solving of special soil problems especially when these have a general significance in the state. Inquiries regarding such assistance may be addressed to the county farm advisor in the county where the property is located or to the Agricultural Extension Division, University of California, Berkeley.

In attempting to solve a practical problem of soil management, it is always useful to consult the farm advisor, when in doubt. He can suggest the best method of seeking any useful knowledge in possession of the Experiment Station, if his own information is incomplete.

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